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Head of Department:
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Scientific Workshop on

FUNDAMENTALS AND MODELING OF LASERS AND ULTRASHORT PULSE INTERACTIONS

Co-Chairs: J. G. McInerney and J. V. Moloney
Department of Physics and Institute for Nonlinear Science
University College, Cork, Ireland

20-25 July 1997

ADVANCE PROGRAMME AND COMPENDIUM OF ABSTRACTS

Keynote addresses

Semiconductor Fundamentals

High Power Semiconductor Lasers

Ultrashort Pulse Interactions

Control and Chaos

Control of Lasers

Semiconductor Laser Dynamics

Overview and synthesis of topics

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The Final Proceedings for Fundamentals and Modeling of Lasers and Ultrashort Pulse Interactions, 4 August 1997 - 8 August 1997

The Topics covered include: Interaction of light with semiconductor media; laser simulation models; nonlinear control strategies for semiconductor laser output; high brightness, wide aperture laser sources.

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PROGRAMME

DAY ONE: MONDAY, 21 JULY

KEYNOTE ADDRESSES & SEMICONDUCTOR FUNDAMENTALS

8:45 – 9:00am — Opening Remarks –J. Moloney & J. McInerney

Session 1 Chairman: Dr. C. M. Stickley (EOARD)

9:00 - 9:45 am	Stephan W. Koch, *Gain/Absorption in Semiconductors*
9:45 - 10:30 am	Peter Blood, *Modelling VisibleEmitting Diode Lasers*
10:30 - 1 1:00 am	Break
11:00 - 11:45 am	Hyatt Gibbs, *Semiconductor Microcavities from Normal-Mode Coupling to Lasing*
11:45 - 12:30 pm	Alan Miller, *Excitonic Optical Nonlinearities in MQW Semiconductors*
12:30 - 1:30 pm	Lunch

SESSION2: HIGH POWER SEMICONDUCTOR LASERS

Chairman: A. Gavrielides (Phillips Laboratory)

1:30 - 2:15 pm	James N. Walpole, *High-Power 1.3-μm InGaAsP/InP Lasers and Amplifiers with Tapered Gain Regions*
2:15 - 3:00 pm	Malcolm Wright, *Dynamics of Broad Area Quantum Well Semiconductor Lasers*
3:00 - 3:30 pm	Break
3:30 - 4:15 pm	Cun-Zheng Ning, A *First-Principles Approach to Semiconductor Laser Modeling*
4:15 - 5:00 pm	John McInerney, *Dynamics of MOPA Semiconductor Lasers*

DAY TWO: TUESDAY, 22 JULY

ULTRASHORT PULSE INTERACTIONS

Session 1. Chairman: J. Socolar (Duke University)

9:00 - 9:45 am	Eric Mazur, *Femtosecond Laser Induced Optical Breakdown in Solids and Liquids*
9:45 - 10:30 am	David J. Hagan, *Beam Coupling with Chirped Laser Pulses in Dielectric Media*
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9:45 - 10:30 am	Nicholas Ercolani, *A Survey of Some Recent Results on Control of PDEs*
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2.30 pm	Tour
7:30 pm	Workshop Dinner in Actons Hotel, Kinsale

DAY 4: THURSDAY, JULY 24

CONTROL OF LASERS

Session 1. Chairman: J. Walpole (Massachusetts Institute of Technology)

9:00 - 9:45 am	Joceline Lega, *Controlling Optical Turbulence*
9:45 - 10:30 am	William J. Firth, *Control of Pattern Formation and Spatio-Temporal Disorder in Nonlinear Optics*
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11:00 - 11:45 am	Robert Harrison, *Low-Frequency Instabilities and Chaos of External Cavity Semiconductor Lasers*
11:45 - 12:30 pm	C.K.R.T. (Chris) Jones, *Complex Behavior of Optically Injected Semiconductor Lasers*
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2:30 – 2:45 pm	Peter O'Brien, *Imaging of Curved Facet and Broad Area Semiconductor Lasers*
2:45 – 3:00 pm	Break
3:00 – 4:15 pm	Discussion Session

DAY FIVE: FRIDAY, 25 JULY

SEMICONDUCTOR LASER DYNAMICS

Session 1. Chairman: H. Gibbs (University of Arizona)

9:00 - 9:45 am	Jesper Moerk, *Mode-Coupling and Low-Frequency Fluctuations in External Cavity Laser Diodes*
9:45 - 10:30 am	Vasillios Kovanis & Athanasios Gavrielides, *Encoding and Decoding Messages with Chaotic Lasers*
10:30 - 11:00 am	Break
11:00 - Noon	Discussion and Wrap-up

PROGRAMME

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4:15 - 5:00 pm — John McInerney, *Dynamics of MOPA Semiconductor Lasers*

GAIN/ABSORTPION IN SEMICONDUCTORS IN SEMICONDUCTORS

Stephan W. Koch
University of Marburg/Germany

A microscopic theory is discussed which allows us to compute the optical response of semiconductor materials. The theory consistently includes the many-body Coulomb interactions leading to bandgap renormalization, excitonic effects, as well as polarization dephasing, carrier relaxation etc. After an outline of the theory examples for a variety of semiconductor materials are discussed and comparisons with recent experimental results are shown.

MODELING VISIBLE-EMITTING DIODE LASERS

Peter Blood
Department of Physics and Astronomy
University of Wales Cardiff

Laser diodes operating in the spectral region between red and blue pose a number of challenges for reliable device modeling, many of which are of fundamental origin and are associated with the electronic properties of wide gap materials. In these materials there are strong Coulomb interactions which affect the recombination and gain-generating processes, high effective masses which affect the relation between confined state energies and well width, low carrier rnobilities and large hydrogenic impurity ionization energies. These fundamental properties will be reviewed for both red-emitting A1GaInP and blue-emitting A1GaInN structures.

Recent work in collaboration with Wen Chow at Sandia Labs comparing experimental gain spectra for GaInP quantum well laser structures with "many-body" calculations will be presented. Model calculations at Cardiff of the total threshold current of these devices obtained from self-consistent numerical solution of Poisson's equation and the current continuity equations for the complete device structure will be described. The results are in excellent agreement with experirmental data for the threshold current as a function of temperature and role of the acceptor ionization energy in achieving this agreement will be discussed. The concept of Fermi level pinning at the laser threshold has been explored using these models and it has been shown that serious errors may arise in the determination of optical mode loss from the external differential efficiency as a function of cavity length. These ideas are supported by experimental results and have led to a clearer interpretation of the internal differential quantum efficiency measured above threshold.

The implications of this work for the modeling of the blue-emitting laser diodes will be discussed.

SEMICONDUCTOR MCROCAVITIES: FROM NORMAL-MODE COUPLING TO LASING:

Hyatt Gibbs
Department of Optical Sciences
University of Arizona

Semiconductor rnicrocavities will be described which exhibit record vacuum Rabi splitting-to-linewidth ratios because of the narrow linewidth of the InGaAs/GaAs quantum wells grown inside the high-finesse GaAs/A1As cavity. When one of these microcavities with the exciton peak and cavity mode in resonance is excited resonantly or nonresonantly with cw or 100-fs-pulsed light, the two transmission peaks go down with negligible change in the splitting, At sufficiently high density the exciton-cavity coupling becomes too weak, and the system returns to the perturbative regime of irreversible emission yielding a single Fabry-Perot peak which results in the usual vertical-cavity lasing above threshold. Transfer matrix calculations of the niicrocavity transmission using measurement of the nonlinear absorption of the exciton resonance show that this unusual nonlinear behavior results from the fact that the exciton line broadens with little reduction in oscillator strength. The broadening increases the absorption at the normal-mode-coupling peaks thus reducing their transmission, and the splitting changes very little because the oscillator strength is nearly constant. The data are also in agreement with a microscopic theory for excitonic nonlinearities and light propagation in semiconductor microcavities for varying electron-hole densities. The nonlinear susceptibility of quantum confined excitons is determined from quantum kinetic equations including dephasing due to carrier-carrier and polarization scattering.

The luminescence and transmission have also been studied as a function of cw and 100-fs excitation intensity and as a function of exciton-cavity detuning . For the cavity tuned to an energy above the exciton, the upper polariton emission is weaker at low excitation; with higher excitation the lower polariton emission clamps, whereas the upper polariton emission grows rapidly. A crossover occurs at a density similar to that needed to go from two peaks to one peak in the nonlinear transmission data described above. This curious behavior is in agreement with a full quantum analysis of the luminescence properties found by studying both the field dynamics and the many-body system of carriers microscopically.

EXCITONIC OPTICAL NONLINEARITIES IN MOW SEMICONDUCTORS

Alan Miller
School of Physics and Astronomy
University of St. Andrews, Scotland

Excitonic optical nonlinearities are of interest for optical switching, mode-locking elements in lasers, the control of solitons in communications systems and in optical modulators employing the quantum confined Stark effect. This talk will present quantitative measurements of the different contributions to excitonic optical nonlinearities in multiple quantum well semiconductors at room temperature using time resolved ultrashort pulse laser techniques. Phase space filling, screening and broadening are distinguished in pump-probe measurements using linear and circular polarizations and by contrasting results obtained using picosecond and femtosecond pulses. Carrier transport properties in quantum wells have been investigated using both amplitude and polarization transient gratings. Experiments will be described which uniquely determine both the in-well electron and hole mobilities. The results discussed in terms of the different contributions to the excitonic nonlinearities and the detailed band structures.

HIGH-POWER 1.3-μm InGaAsP/InP LASERS AND AMPLIFIERS WITH TAPERED GAIN REGIONS

James N. Walpole
Lincoln Laboratory,
Massachusetts Institute of Technology

Diode lasers have been fabricated in InGaAsP/InP multi-quantum-well material grown by atmospheric-pressure organometallic vapor-phase epitaxy with an active optical cavity consisting of a ridge wayeguide region coupled to a tapered gain region. Over 1W of CW output power was obtained with 85% of the power in the central lobe of a diffraction-limited far-field radiation pattern.

DYNAMICS OF BROAD AREA OUANTUM WELL SEMICONDUCTOR LASERS

Malcolm Wright
Semiconductor Laser Branch
AF Phillips Lab/LIDA and Center for High Technology Materials
University of New Mexico

Current research at the Semiconductor Laser Branch of the AF Phillips Laboratory centers on understanding the physics of semiconductor laser sources with specific emphasis on the limitations for high power operation. Some recent results will be discussed.

Dynamics of temporal instabilities in tapered broad-area semiconductor master oscillator/power amplifier devices have been experimentally investigated and simulated theoretically. Coupled-cavity modes are evident in the spectra along with multigigahertz self-pulsations. From a time-dependent coupled-wave model, the effect of the residual facet reflectivity is shown. Using this model, a tradeoff can be made between the front grating strength in the DBR section of the master oscillator and the antireflection facet coating requirement. Increased stable operation at high powers is then possible. Alternatively, with a full spatio-temporal model, lateral mode instabilities can also be modeled.

Spontaneous emission spectra have also been obtained from semiconductor quantum well lasers of varying geometry and epitaxial design. Model gain or nonlinear gain effects such as carrier heating can be inferred from the spectra obtained through the side wall of the device. Using this method for collection of spontaneous emission, the effect of quantum well dimensions on carrier heating in single quantum well InGaAs or GaAs active regions was investigated. Carrier heating was only observed in InGaAs samples at cryogenic temperatures with minimal distortion of the carrier distribution to higher energies otherwise. This result was compared to spectra from nonlasing samples where much higher carrier densities could be reached. Measurements of other fundamental properties of interest such as the Fermi energy separation will also be discussed.

A FIRST-PRINCIPLES APPROACH TO SEMICONDUCTOR LASER MODELING

Cun-Zheng Ning
Arizona Center for Mathematical Sciences
Department of Mathematics University of Arizona

:Starting from microscopic theory for the interaction of light with semiconductor quantum structures, including many-body interactions and bandstructure information, we construct an effective set of equations that captures many important features of optical response functions needed for modeling high power diode lasers. The model will be demonstrated by the example of monolithically integrated MOPAs. Results of MOPA operation under Dc and modulated pumping conditions will be presented.

DYNAMICS OF MOPA SEMICONDUCTOR LASERS

John Mclnerney

Physics Department

University College Cork

Ireland

Monolithically integrated Flared Amplifier Master Oscillator Power Amplifier (MFA-MOPA) are studied theoretically using a high resolution computational model which resolves time as well as longitudinal and transverse space dependences and includes Lorentzian gain and dispersion dynamics. The simulations show that, by altering the linear flare of the power amplifier into a nonlinear, trumpet-shaped flare to overlap the gain region to the expanding field, the instability threshold of the MOPA is increased by ~2 for single-longitudinal, single-transverse mode operation and ~3 for single-transverse mode operation. This enables the MOPA to maintain a stable, near-diffraction limited output beam for higher currents before the onset of transverse instabilities. Thus the trumpet-flared amplifier enables the MOPA to emit an output beam of significantly higher power and brightness. This increased stability is due to a large reduction in feed-back from the output facet of the trumpet shaped MFA-MOPA.

DAY TWO: TUESDAY, 22 JULY

ULTRASHORT PULSE INTERACTIONS

Session 1. Chairman: J. Socolar (Duke University)

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FEMTOSECOND LASER INDUCED OPTICAL BREAKDOWN IN SOLIDS AND LIQUIDS

Eric Mazur
Division of Applied Sciences
Harvard University

We use tightly-focused 100-fs laser pulses to induce optical breakdown and initiate micro-explosions inside transparent solids and liquids. The rapid energy deposition creates high temperatures and pressures causing an explosive expansion. However, the extreme conditions are highly confined and can be precisely controlled We examine the resulting 200-250-nm diameter structures in fused silica, quartz, and sapphire using optical microscopy, atomic force microscopy, and scanning and transmission electron microscopy of internal cross-sections. Using time-resolved imaging and scattering we monitor the dynamics from picoseconds to microseconds. The micro-explosions provide novel techniques for internal microstructuring of transparent materials, 3-D optical data storage, and precise photodisruption for eye surgery.

BEAM COUPLING WITH CHIRPED LASER PULSES IN DIELECTRIC MEDIA

David J. Hagan
Physics and Astronomy Department
CREOL
University of Central Florida

In two-wave mixing experiments using chirped, mode locked pulses of approximately 100 fs duration, we observe transient energy transfer in transparent dielectric solids. Such experiments yield signals that are in proportion to the magnitude and response time of the nonlinear refractive index. Deep in the transparency region of dielectrics, the nonlinear refractive index is dominated by the nonlinear motion of bound electrons and atomic nuclei. Hence, provided we can eliminate nuclear effects, the measurement of bound electronic response times may be possible. We expect such times to be in the sub-femtosecond range, which is not (and probably will not ever be) accessible by conventional ultrafast measurement techniques. We will describe the technique, theoretical issues and our latest results in SiO2 and PbF2.

PHYSICAL MECHANISMS FOR THE ARREST OF CRITICAL COLLAPSE OF ULTRASHORT OPTICAL PULSES

J.V. Moloney
Arizona Center for Mathematical Sciences
Department of Mathematics
University of Arizona

Femtosecond duration optical pulses can contain very little energy but still attain peak intensities greater than the material breakdown threshold. The problem becomes particularly complicated when critical self-focusing becomes important. Now the scales in space and time can compress violently until eventually the usual paraxial envelope descriptions of pulse propagation become questionable. In some instances, this compression can be halted by a variety of physical mechanisms.

We will discuss the subtle interplay between group velocity dispersion, nonlinearity, avalanche versus multiphoton ionization instigated breakdown within the usual envelope model approximations. When the collapse filament size approaches the wavelength of light, we adopt a full vector Maxwell model and seek novel nonlinear self-trapped solitary wave solutions. At the high peak intensities achieved it is likely that carrier wave shocking can precede the usual envelope self-steepening. In 1D and 2D, one can distinguish between light bullets (centered at a carrier frequency) and light bubbles (DC central frequency). The talk will compare and contrast the envelope versus vector Maxwell descriptions and discuss open questions with regard to appropriate constitutive relations for such short time optical interactions.

MODULATIONAL INSTABILITY IN BRAGG GRATING STRUCTURES

Alejandro Aceves
Department of Mathematics and Statistics
University of New Mexico

Recent experiments on fiber gratings have demonstrated the formation of nonlinear grating solitons, corroborating earlier theoretical work based on the coupled mode theory. The modeling of the pulse dynamics in these structures also indicates a regime of behavior similar to that of the nonlinear Schroedinger equation (NLSE). Here, we further explore this regime and propose a high-repetition rate pulsed source based on the phenomenon of modulational instability. We discuss how the NLSE predictions compare with the coupled mode equations and with experiments.

EXPERIMENTAL CONTROL OF CHAOS IN SEMICONDUCTOR LASERS

Dan Gauthier
Department of Physics
Duke University

I will review our progress on controlling the temporal dynamics of semidconductor lasers with optical feedback operating in the 'low-frequency fluctuation' regime. The ultrafast time scales, high-dimensional dynamics, and quantum noise all conspire to make this an exceedingly rich control problem.

DAY THREE: WEDNESDAY, 23 JULY

CONTROL AND CHAOS

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OVERVIEW OF MODERN CONTROL THEORY

Arthur Krener
Department of Mathematics
University of California-Davis

A survey of the important problems, concepts and techniques of linear and nonlinear control.

A SURVEY OF SOME RECENT RESULTS ON CONTROL OF PDE'S

Nicholas Ercolani
Department of Mathematics
University of Arizona

Some recently developed pde models of nonlinear optical and fluid systems in which control strategies have been successfully applied will be described. Stability analyses will be presented which assess the robustness of the control.

CONSTRUCTING DATA GENERATED FILTERS FOR CONTROLLING NONLINEAR PARTIAL DIFFERENTIAL EOUATIONS

Ira Schwartz
Naval Research Laboratory
Special Project in Nonlinear Science,
Washington, D.C.

Many physical systems modeled by nonlinear partial differential equations which possess complicated high dimensional behavior have certain states which are unstable and low dimensional. In this talk we present methods which may be used to stabilize these low dimensional states by constructing appropriate data filters. Both theory and experiments will be given.

CRITICAL EXPONENT FOR GAP FILLING AT CRISES

Ying-Cheng Lai,
Physics and Astronomy Department
University of Kansas

The focus of this talk is on crisis of chaotic attractors which is common in nonlinear optical systerms. Specifically, we will describe sudden enlargement of chaotic attractors, an event called the interior crisis. Before the crisis, the asymptotic set of the system is a small chaotic attractor. An interior crisis is triggered by the collision of a small chaotic attractor with a coexisting nonattracting chaotic saddle. After the crisis, the asymptotic set of the system is a larger chaotic attractor, and the original chaotic saddle is converted into part of the larger chaotic attractor. The gaps in-between various pieces of the chaotic saddle are densely filled after the crisis. This is referred to as "gap filling." We argue that gap filling is caused by the birth of an infinite number of unstable periodic orbits which do not exist before the crisis. As a consequence, we expect the topological entropy, which quantifies the number of periodic orbits of a chaotic set, to grow after the crisis. We give a quantitative scaling theory for the growth of the topological entropy. The theory is confirmed by numerical experiments, and it is expected to be UNIVERSAL, i.e., it holds regardless details of the system.

TIME-DELAY FEEDBACK FOR FUN AND PROFIT

Joshua E. S. Socolar
Department of Physics
Duke University

A common problem faced by engineers working with strongly nonlinear systems is that a desired periodic behavior is unstable even though it does represent a solution to the equations of motion. Standard techniques for stabilizing behaviors of this type generally involve comparison of the current state of the system to some externally produced reference signal and subsequent application of appropriate, feedback designed to reduce this difference. In many cases, however, it is impossible to prepare such a reference signal. Instead, one may attempt to utilize the past behavior of the system itself as a reference. The resulting time-delay equations provide an interesting exercise in linear stability analysis (the fun part) that suggests the technique may be effective both for very fast systerms and for spatially extended systems (the profit). In this talk the general concept of time-delay control of unstable periodic orbits will be introduced, with emphasis on issues relevant to the problem of stabilizing traveling waves in wide-aperature semiconductor lasers.

DAY 4: THURSDAY, JULY 24

CONTROL OF LASERS

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2:45 – 3:00 pm	Break
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CONTROLLING OPTICAL TURBULENCE

Joceline Lega
Centre National de la Recherche Scientifique
Institut Non Lineaire de Nice
France

A robust global control strategy, implemented as a spatial filter with delayed feedback, is shown to stabilize and steer the weakly turbulent output of a spatially-extended system. The latter is described by a generalized complex Swift-Hohenberg equation which is used as a generic model for pattern formation in the transverse section of semiconductor lasers. Our technique is particularly adapted to optical systems and should provide convenient experimental control of filamentation in wide aperture lasers.

CONTROL OF PATTERN FORMATION AND SPATIO-TEMPORAL DISORDER IN NONLINEAR OPTICS

William J. Firth
Department of Physics and Applied Physics
University of Strathclyde, Scotland

Pattern formation is a universal phenomenon in nonlinear optics. The coupling of diffraction with optical nonlinearities often leads to stationary or dynamical patterns. Here, we focus on the possibility of controlling the spontaneous evolution of pattern forming systems by means of selective perturbations. We present a new method for the stabilization and tracking of unstable spatial states of a pattern forming optical system. The control has the form of a small spatial modulation of the input pump beam and is derived from the spatial Fourier transform of the output electric field. In Fourier space, pattern states have a simple form consisting of a finite number of equally spaced modes. Using this information the control is constructed by altering the stability of both the undesired and selected patterns and it vanishes once stabilization is achieved Unstable homogeneous solutions, rolls, squares, hexagons and honeycombs have all been stabilized and successfully tracked. In recent work turbulent spatio-temporal outputs have been controlled by the same technique so as to produce stationary, uniform patterns,

LOW-FREQUENCY INSTABILITIES AND CHAOS OF EXTERNAL CAVITY SEMICONDUCTOR LASERS

Robert Harrison
Department of Physics
Heriot-Watt University
Scotland

We report on theoretical analysis and experimental measurement of low-frequency dynamical behavior in a semiconductor laser with single mirror external feedback. The experimental measurements of dynamics are made by using visible InGaAlP semiconductor lasers, operating in single- or multi-modes near the "kink" region in the input-output characteristics. The systems exhibit four fundamental states: low-frequency fluctuations, limit cycle, coherent collapse and DC emission. The dynamics occur on two distinct frequency scales, typically Ghz and MHZ, referred to as high- and low-frequency. In particular, a coexistence of, and switching between, the limit cycle and DC states have been observed. From quantitative measurements we find that the high- and low-frequency components may be decoupled at low pumping current. The dimensionality of the chaos is found to depend on the number of solitary laser cavity modes and is low ($D_2 \approx 2.8$) for nearly single-mode and high ($D_2 \approx 5.6$) for multi-mode operations, respectively, We have performed detailed theoretical and numerical analyses of these observed dynamical phenomena based on the modified Lang-Kobayashi rate equations, which show a good agreement with experimental observations.

Further work on control and synchronization of chaotic dynamics in these semiconductor laser systems is in progress, the result of which will be reported.

COMPLEX BEHAVIOR OF OPTICALLY INJECTED SEMICONDUCTOR LASERS

C.K.R.T. (Chris) Jones
Division of Mathematics
Brown University

We analyze a third-order pendulum equation for the phase difference of the electric field in a semiconductor laser subject to optical injection, as derived by Erneux, Kovanis, Gavrielides and Alsing. We investigate its complex dynamics by deriving an associated 3-D Poincare map that is valid near resonances. We observe the presence of surfaces on which this map reduces to a one-dimensional map the graph of which is close to that of the familiar quadratic map. The phase equation will therefore inherit most of the dynamics of the quadratic map, the most obvious being the period doubling route to chaos. This is joint work with Jean-Michelet Jean-Michel.

HIGH FREQUENCY FLUCTUATIONS IN SEMICONDUCTOR LASERS WITH OPTICAL FEEDBACK

G. Huyet

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National University of Ireland

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Semiconductor lasers with optical feedback were first considered in order to narrow the laser linewidth. However, for a moderate feedback level, the laser output becomes unstable and its linewidth abruptly increases. In this regime, the light emitted by the laser displays power drop-outs at a time scale much larger than the reinjection time and/or the relaxation time of the laser, thus they are usually called Low Frequency Fluctuations (LFF). Among the many studies of the LFF regime, there is little experimental information available about the high frequency behaviour of the laser intensity. This is mainly due to the difficulty of digitising non-periodic signals having two extremely different time scales. In such a system, statistical measurements are more appropriated. In our experiment, we analyse the temporal evolution of the light emitted by the laser with a Schottky diode and a sampling head which is inserted in a Communication signal analyser. With this experimental set-up, we are able to characterise the laser fluctuations up to 23 Ghz. The probability distribution of the laser intensity show the presence of high frequency fluctuations. However, we will show that these fluctuatations clearly differ from the one predicted by the LK equations. We will also present measurement of the probability distribution of the laser intensity vs time after power drop-outs. With this last measurement, we will show that we can resolve the full dynamics. In particular, we will show power drop-outs without relaxation oscillations.

Imaging of Curved Facet and Broad Area Semiconductor Lasers

Peter O'Brien and John McInerney

Department of Physics,
University College Cork,
National University of Ireland,
Ireland.

We have imaged the interiors of curved facet and broad area semiconductor lasers operating at 980 nm. Negative branch curved facet devices were fabricated using a dry etching process, Fig.1. Analysing the spontaneous emission through the substrate we observed an internal focal point, Fig.2. The lateral temperature profiles for various currents were obtained for broad area devices by measuring the shift of the spontaneous emission peak, Fig.3.

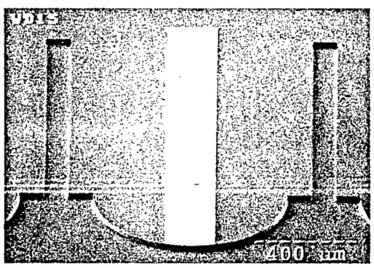

Fig. 1 Scanning Electron Microscope image of etched curved facet laser.

Fig.2 Image of curved facet laser cavity.

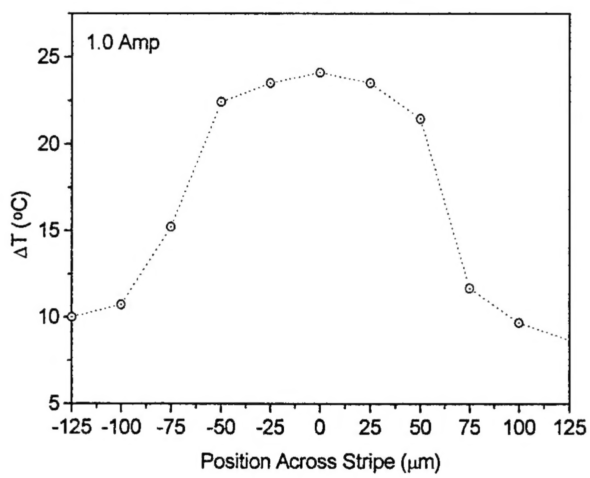

Fig.3 Lateral temperature profile for a 100 um wide device at 1 Amp.

DAY FIVE: FRIDAY, 25 JULY

SEMICONDUCTOR LASER DYNAMICS

Session 1. Chairman: H. Gibbs (University of Arizona)

9:00 - 9:45 am	Jesper Moerk, *Mode-Coupling and Low-Frequency Fluctuations in External Cavity Laser Diodes*
9:45 - 10:30 am	Vasillios Kovanis & Athanasios Gavrielides, *Encoding and Decoding Messages with Chaotic Lasers*
10:30 - 11:00 am	Break
11:00 - Noon	Discussion and Wrap-up

MODE-COUPLING AND LOW-FREQUENCY FLUCTUATIONS IN EXTERNAL CAVITY LASER DIODES

Jesper Moerk
Mikroeletronik Centret
Technical University of Denmark

The role which mode-coupling plays in determining the oscillating mode of a semiconductor laser and ensuring its stability is illustrated for the case of an external cavity laser diode. We show that the tendency of a laser to oscillate in the mode with lowest threshold gain is counteracted by self-stabilization due to mode-coupling. For an external cavity laser at low bias current and with moderate to strong optical feedback the occurrence of low frequency fluctuations (LFF) can be seen as a consequence of a reduced self-stabilization effect. The picture supports our previously developed description of LFF as bistable switching followed by iterative shifts of the laser spectrum towards the mode with lowest threshold gain. The description is shown to agree with measurements of the time evolution of the laser spectrum during LFF.

ENCODING AND DECODING MESSAGES WITH CHAOTIC LASERS

Vasillios Kovanis and **Athanasios Gavrielides**
Nonlinear Optics Center of Technology
Phillips Laboratory/LITN
University of New Mexico

There has been great interest in the use of chaotic signals as carriers of analog and digital information over the last few years. Recent experiments have demonstrated that using chaos to communicate is practically feasible with electronic circuits. In this talk we will present investigations of the structure of the strange attractor of a chaotic loss-modulated solid-state laser utilizing return maps based on a combination of intensity maxima and interspike intervals, as opposed to those utilizing Poincare sections defined by the intensity maxima of the laser alone. We found both experimentally and numerically that a simple, intrinsic relationship exists between an intensity maximum and the pair of preceding and succeeding interspike intervals. In addition, we will numerically investigate encoding messages on the output of a chaotic transmitter laser and its subsequent decoding by a similar receiver laser. By exploiting the relationship between the intensity maxima and the interspike intervals, we demonstrate that the method utilized to encode the message is vital to the system's ability to hide the signal from unwanted deciphering. In this talk alternative methods will be detailed in order to encode messages by modulating the magnitude of pumping of the transmitter laser and also by driving the loss modulation with more than one frequency.